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Positional damages of peripheral nerves of the upper extremity during anesthesia and the problem's solution

Biomechanical investigation of the arm threat

Summary of promotion thesis for obtaining
a degree of Doctor of Medicine
Speciality – Anesthesiology and Reanimatology

Riga, 2011

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Research was carried out at:

- Department of Anaesthesiology and Reanimatology of Riga Stradiņš University
- Department of Histology and Departement of Pathology of Riga Stradiņš University
- Riga hospital No.2, Ventspils and Jelgava regional hospitals
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Topicality of the study

Surgery has become one of the most important healthcare branches with totally 234 millions of surgical operations per year worldwide (Weiser, 2008), and this number even exceeds the world annual birth rates (Ronsmans, Graham, 2006). It is known that surgical intervention can help and save lives in the case of many pathologies but it is accompanied by the high complications risk. Between the mentioned number of operations, 7 millions annually develop severe surgical complications and 200 000 patients in European countries and 1 million worldwide dies from these. Recently signed declaration of Helsinki on the patient safety during anaesthesia calls everybody who participates in the perioperative process to help decrease the number of complications (Mellin-Olsen et al., 2010).

The percentage of morbidity and mortality is very variable depending on the affiliation of the country to rich or poor region. The statistics of the developed countries shows that the perioperative mortality varies between 0.4 and 0.8% but the number of complications - between 3 and 17% (Gawande et al., 1999, Kable et al., 2002). The incidence of these complications is higher in underdeveloped countries (Bickler, Sanno-Duanda, 2000, Yi, Ng, 2002, MsConkey, 2002). It is also known that development of the certain part of complications is determined by the patient position with direct or indirect damages of the organs and tissues. Peripheral nerve damages due to incompletely assured position during the operation and anaesthesia manipulations should be highlighted separately.

Surgical intervention is associated with a compulsory position of the patient to ensure surgical or anaesthesia manipulations. Patient's positioning requires much attention and knowledge. Good operation position ensures the optimal approach for surgeon to operation area, decreases blood loss and reduces compression on the nerves, soft tissues and also cardiopulmonary system and relieves functional disorders (Bortolussi et al., 1991, Martin, 1992, Rhodes et al., 1972, Ward et al., 1966, Hedenstierna, 1990). Each position has its individual, specific risks and the benefits of them should be compared with the threats. Any operation position may also potentially cause undesirable effects, especially if the position exposition time is long enough. The actual incidence number of the postoperative neuropathies un-related to regional anaesthesia is unknown because these may be very transient – lasting even some hours or days - and therefore are not presented in a medical card. We can judge

about the approximate incidence of the postoperative neuropathies from some sources (Dhuner 1950, Parks 1993, Britt et al., 1964, Boet 1986), and their incidence is estimated as totally 0.1% of numbers of anesthesias; the ulnar neuropathy is observed most commonly – in 0.04% (Warner et al., 1994, Drizenko, Scherpereel 1997). According to *ASA closed claim study* analysis of 1990, peripheral nerve damages compose 15% or 227 patients from totally 1541 submitted claims concerning postoperative complications (Keats 1990). Data from ASA closed claim study aggregated in 1994 about the period from 1970 to 1994 indicate that increasing safety requirements during anesthesia reduces mortality and such severe complications as cerebral ischemia, but the percentage of peripheral postoperative neuropathies remains constant - 15-18% (Cheney et al., 1999, Cheney 1999). Although these data do not present the real number of complications but relates only to the number of submitted legal claims that is actually much lower and, according to the opinion of insurance companies, composes approximately tenth of the actual number of complications. The reason of it is the fact that one part of damages regresses completely, and direct reconciliation about compensation of the other part is found (Drizenko, Scherpereel 1997). Between all damages of separate neural structures, a damage of *n.ulnaris* occurs most often (28%) following by the damage of *plexus brachialis* (20%), roots of *plexus lumbosacralis* 16%) and spinal cord (13 %) (Kroll et al., 1990). It should be also noted that the patients suffering from chronic vascular diseases and topical disorders are usually more predisposed to these acute damages, as well as to rabdomyolysis or compartment syndrome, when using tourniquet for a long time or compressing the nerve against arm or leg (Upton, 1973). However, there are still much unknown in the developmental pathophysiology of postoperative neuropathy of the upper extremity, and this problem was investigated during this scientific work and the solutions for decreasing of the risk were searched.

The study's data shows that by purposeful actions it is possible to prevent approximately half of all surgical complications (Gawande et al., 1999, Kable et al., 2002). For example, the efforts of recently years to decrease surgical infection by timely antibacterial prophylaxis, and using the action protocols worked out by the scientific societies to avoid anesthesia errors have given the significant results (Dellinger et al., 2005, Classen et al., 1992, Runciman, 2005). In the recent years, the "Evidence-based Medical Practice" has become a scientific basis of therapeutic practice; it is based on the introduction of different methods in practice only after

acquisition of incontrovertible scientific evidences. This continuously growing base of evidences confirms that exactly the team work in surgery improves outcome and well-coordinated action of different specialists in an operating room significantly decreases the number of complications (Mazzocco et al., 2008, Lingard et al., 2008). Therefore the World Health Organization (WHO) in 2008 published the guidelines imposing conditions for patient care during surgery to provide patient safety and to ensure that these conditions could be fulfilled in the countries with different economical situation (WHO, 2008). These guidelines have been an encouragement for the working out practical guidelines which are developed by cooperation of doctors from different countries. The first large trial after introducing the "surgical safety checklist" or the control-list into practice simultaneously both in the developed and underdeveloped countries surprised by the results of reduced complications; these were not based on the additional technical or material improvements but only on the coherent work of all the team of surgeons, anesthesiologists and nurses in the operating room. After introducing the checklist into eight big word hospitals (*Toronto, New Delhi, Amman, Auckland, Manila, Ifakara, London, Seattle*), within one year all kinds of complications decreased from 11 to 7% ($p<0.001$) and the mortality decreased from 1,5 to 0.8% ($p=0.003$). The statistical incidence of wound infection and re-operations also significantly decreased ($p<0.001$ and $p=0.047$) (Haynes et al., 2009). These interesting data urge to review the daily habits in the operation room and make improvements.

Today, the modern operation department is inconceivable without a big and also expensive material-technical base. Operation tables with auxiliary devices for patient alignment into an operation position, additional surgical equipment such as endoscopes, microscopes, lasers, technique for surgical manipulations and complicate anesthesiology and transfusiology equipment requires very much space in the operation room (Ullrich et al., 1997). Personnel of the operation room should supervise all the technique that provides good work result. However, the main goal of the personnel and technique is to help the patient whose body is often difficult to monitor during all the operation because the sterility and homeostasis must be ensured and especially it relates to extremities support. The same situation is often observed in the pre-anesthesiology period when during the first anesthesiology manipulations, for instance - for the regional anesthesia, improvised devices or surgical tables instead of the appropriate arm supports is used for the arm or leg support. Development of the

appropriate, universal arm support would improve the comfort of patient and personnel and patient safety because exactly the compression neuropathy is the most frequent reason of the postoperative neuropathies (Prielipp, 1999).

From the perspective of neurological complications the checklist offered in 2009 includes all those actions that should be done by anesthesiologist before and during the operation. For example, recording of the time of applying and removing a tourniquet and monitoring the pressure, assessment of position of the patient body and extremities at the beginning of operation and in each operation stage when changing body position, as well as assessment of the neurological risk. Monitoring of all support points is an important criterion for providing patient safety (Desmonts, 1994). For instance, the perioperative compression injury of *bulbus oculi* belongs to very serious compression injuries (Hollenhorst, 1954).

Interdisciplinary allocation of responsibilities in the operation room is a basis of successful providing of the patient safety, but for this purpose all actions of the personnel should be well-documented. The assessment of neurological risk, better understanding of the neuropathies' pathophysiology and requirement to show the positioning in the operation documentation would significantly improve patient safety and decrease the incidence of neurological complications.

Aim of the work

To investigate peculiarities of the damage of *plexus brachialis* during arm abduction and work out the rules of positioning the patient arm to improve patient comfort and decrease the neurological complications during operations and anesthesia manipulations.

Tasks of the work

1 Evaluate the morphological changes of neural structures during the strain deformation and arm hyperabduction.

2. Specify the correlation between the compression of the shoulder's neurovascular bundle and shoulder position, as well as determine the main compression points of the bundle.

4. Develop the technical auxiliary devices for improvement of the arm positioning.

5. Based on the clinical evidences, determine the neurological risk factors for extremities positioning and possible methods for their reducing.

6. Work out the recommendations for positioning the patient's upper extremity during the surgical operation.

Hypothesis of the work

1 .Development of the arm neuropathies during the standard operation positions is based on mixed mechanism of the strain of neural bundle and compression injury.

2. Introducing of the positioning algorithm, checklist and assessment of the neurological risk may reduce the risk of postoperative neuropathies.

Scientific and practical novelty of the work

1. New data are obtained about the pathogenesis of neural damage during the arm abduction.

2. Technical auxiliary devices are developed for the improvement of arm positioning during the surgical operation or anesthesia manipulations.

3. Risk scale for the determination of perioperative neurological risk and for the prevention of complications is developed.

4. New method for the tissue pressure measurement is developed.

Design and amount of the work

The work is written in Latvian language, in classical dissertation form; it consists of the introduction, literature review, sections about the material and methods, results, analysis of the obtained results and discussion, conclusions, references and appendix. Analytically-illustrative and statistical material is showed in 61 figures and in 11 tables. Reference contains 298 titles.

Bases of the work and used equipment

The work has been done in the Riga hospital No.2, Venspils and Jelgava regional hospitals, State Centre for Forensic Medical Examination, in the Department

of Anesthesiology and Reanimatology and in the Department of Pathology and Department of Histology of RSU.

There was used portative ultrasound device "Sonosite Micromaxx" (USA), regional anaesthesia station "Locoflex 4E" (Latvia) and manometer Keyence AP-30 (Japan). Statistical processing of the study data was done in the Department of Physics of Riga Stradins University using the software SPSS 16.0 (Company SPSS, USA).

Approbation of the study

The materials of the promotion work were reported in one Latvian and in three international conferences and congresses. Names of the reports are attached at the end of the summary.

Publications about the work theme

Results of the promotion work is showed in two monographs, in Chapter in the textbook and in six quotable scientific publications. The list of publications is attached at the end of the summary.

Innovations, patents an introducing of new devices

During work time, 9 patents were submitted, including one international. Three new devices are developed and introduced into practice. The list of patents and devices is attached at the end of the summary.

Material and methods

During the work, four clinical studies were carried out, the technical auxiliary devices for the arm positioning were developed and the scale of neurological risk factors was worked out.

1. Study on the strain and deformation of the neurovascular bundle

To investigate the mechanisms of strain and compression deformation during the arm abduction, autopsy material from seven cadavers whose death has been found 6-24 hours ago was used. First of all, the strain deformation of *plexus brachialis* and peripheral nerves forming it were investigated, and secondly, by the original patented method the pressure of the surrounding tissues on the neurovascular bundle was

directly measured placing the arm in the abduction position of 45, 90, 120, 150 and 180 degrees characteristic for anesthesia.

During the first study part, strain deformation of the peripheral nerves of *plexus brachialis* at the level of *sulcus bicipitalis* was investigated. At first, the neurovascular bundle was prepared bilaterally in the middle third of *humerus* and *nervus medianus, nervus ulnaris* and in one case - also *nervus cutaneus brachii superficialis* were dissected. Each of the separated nerves was transfixed with needles at two points with approximately 20-30 mm between each other. After transfixation of the nerve, position of the arm was changed in abduction positions of 45, 90, 120, 150 and 180 degrees. In each abduction position, a photographing method and *AutoCad* software was used for determination of the length changes of the nerve segment.

During the second study part, the authors'patented direct tissue pressure measurement method was used for determination of the deformation pressure of the neurovascular bundle. Tissue pressure was determined by using the angioplasty catheter and by measuring the changes in its dilatation balloon. The patent request is submitted about this used method – for the "Device for measuring the tissue pressure" (Vasilevskis, Vanags, 2010). The angioplasty balloon- catheter connected with the manometer through the plastic tubing was used. The trident and the syringe are used for creation of pressure in the system. To measure the pressure, *v. brachialis* in the dissected *sulcus bicipitalis* was catheterized at first. The angioplasty balloon-catheter (*Fox plus, Abbott*) was used with a length of dilatation cylinder of 40 mm and diameter of 12 mm when inflated; it corresponds to the mean distance between the first rib and clavicle, as well as to the diameter of *vena* subclavia during the inspiration phase (Matsumura et al., 1997, Remy-Jardin, 1997). The catheter was initially introduced up to the attachment site of *mm.scaleni* to the clavicle.

At the beginning of measurements, the catheter with trident was attached to the pressure manometer (model *Keyence AP-30*, Japan) and the balloon was inflated with air up to the level of 20 kPa (150 mmHg) or initial diameter of 12 mm. Then, the changes of pressure in the catheter balloon were recorded changing arm position from the 0 to 90, 120, 150 and 180 degrees angle. The measurements were done in kPa, but conversion to mmHg was performed for easier data interpretation. The changes in pressure were measured in absolute numbers but the relative pressure changes in the dilatation balloon changing the arm position were analyzed. The changes in pressure present a pressure of surrounding tissues on the neurovascular bundle during the arm

abduction. The measurements were performed on both hands for 5 times pulling back the balloon each time for 3 cm while 15 cm were pulled back and the level of humeral head was achieved. Maximal change of pressure was considered the most significant factor in the potential compression of the neurovascular bundle and was used in the analysis.

During the third study part, using light and electron microscopy the changes in neural fibers and collagen structures provoked during the strain deformation on the test bench were evaluated. After the strain tests, additionally 7 cm fragment of *n.medianus* was dissected from the cadaver. 2 cm of the obtained sample were used as a comparative material. 5 cm were inserted in the test bench with inner distance of 30 mm. After fixation of the nerve in the jaws of test bench, the fragment was extended for 15 percents or 4.5 mm using a screw and the distance was fixed by the sliding caliper. Maintaining this stretching, the nerve sample together with the test bench was immersed into cell-stabilizing *Custodiol* solution and left for 3 hours exposition. After 3 hours, one part of the nerve was placed into glutar-aldehyde solution for further analysis under the electron microscope, but the other – further fixed in the formaldehyde solution for 24 hours to observe by the light microscope.

Preparation of the nerve sample for the light microscopy

Two nerve samples were prepared for the examination by light microscope. The first one was a control sample obtained from the nerve that was not stretched and the second one – that after the three-hour 15% stretching on the special test bench. In both cases the parallel-oriented tissue samples perpendicular to nerve longitudinal axis were obtained. All prepared samples were placed in the labeled boxes, fixed in neutral buffered formalin and exposed to further dehydratation under alternating overpressure and vacuum in the tissue processor *Tissue-TekVIP5* (*Sakura Finetek Inc., Torrance*, USA) using a growing-concentration analytically pure isopropanol and xylene (*Sigma-Aldrich, Steinheim*, Germany) according to the Tissue Processing Program for Diagnostic Laboratories (*Gamble et Wilson*, 2002). The tissues samples were saturated with melted Paraplast and embedded in the Paraplast blocks (*Gamble et Wilson*, 2002). From the obtained blocks using the microtome *Microm HM 360* (*Microm Int., Walldorf*, Germany) the sections of 5 micrometers in thickness on the electrostatic slides *Histobond* (*Menzel Glasser, Braunschweig*, Germany) were prepared; these were stained according to the Hematoxylin-Eosin method (*Gamble et Wilson*, 2002) to get an overview.

Preparation of the nerve sample for the electron microscopy

Transmission electron microscope (TEM)

The tissue material for the electron microscopic examination was crushed in 1 mm^3 pieces and fixated in 2.5 % glutaraldehyde solution in 0.1 M phosphate buffer (pH=7.4) for 2-4 hours at 4°C. Additional fixation was performed by 1% osmic acid in 0.1 M phosphate buffer for 1 hour at 4°C. The tissue material was dehydrated by ethylic spirit with growing-concentration (50°, 70°, 80°, 90°, 96° and 100°) and then embedded in the mixture of Epon epoxy resin. After evaluation of the 1 μm half thin slides under the light microscope, the location of the tissue material suitable for the electron microscopic analysis was chosen to prepare 60-80 nm ultrathin slides for analysis in the JEOL Company manufactured transmission electron microscope JEM 1011.

Scanning electron microscope (SEM)

The material was fixed in 2.5 % glutaraldehyde solution and 1% osmic acid accordingly to the method. Before the tissue drying in the critical point, they are dehydrated in the growing-concentration acetone (60°, 70°, 80°, 90°, 90.5°). Drying in the critical point was provided by the corresponding CO_2 pressure and water temperature. The dry samples were attached to the special holder by the silver pasta and coated with layer of gold in the cathode frother. The prepared tissue holders with the samples were placed in the electron microscope JSM-6490LV and were examined at a voltage of 25kV in a magnification of 100x – 20 000x.

2. Study on the arterial flow in the arm hyperabduction positions with shoulder elevation and horizontal flexion

38 patients – 21 women and 17 men of an average age of 64.2 ±13.5 years hospitalized in the Departments of Traumatology and Orthopedics due to different traumas or orthopedic diseases or in the Cardiovascular Department due to coronary heart disease and different chronic circulatory disorders participated in the open, comparative study.

Patients which can walk and according to the study protocol can do arm hyperabduction tests when lying on the examination table **were included in the study**. Defined **exclusion criteria** were following: inability to lay supine all the examination time, inability to do the arm abduction attempt up to the position of 120°,

patient's weight more than 100 kg, trauma of the shoulder zone or pervious surgery on the examined side, arrhythmias and atrial fibrillation, as well as a hypoechogenic type of the tissues that prevents accurate doplerographic examinations. In one proportion of the patients only one side was examined but in the others it was possible to examine both sides and this depended on ability of the patient to lay supine for a long time. The completed examination was considered an ultrasonographic examination of *arteria subclavia* and *arteria axillaris* of one patient side. The effect of hyperabduction of the upper extremity, shoulder elevation and arm horizontal flexion on compression of the neurovascular bundle was evaluated during the study. For this reason, the maximal systolic flow in *arteria subclavia* and *arteria axillaris* was registered at the hyperabduction positions characteristic for a surgical operation and anesthesia.

In the final processing the data of the 36 patients obtained in 45 measurements series were included. Two patients were excluded from the study because atrial fibrillation was detected in them during the examination.

Equipment and protocol

The work was done by the portative ultrasound device „Sonosite MICROMAXX" with a 6-13 MHz linear probe. The changes in maximal systolic flow rate (Vsmax) in the arteries were recorded in the special protocol. Examinations were standardized and they were done in the predetermined positions of arm hyperabduction combining with different shoulder positions in a horizontal plane.

Two positions of arm abduction used during anesthesia were chosen - 90° and 120°. The results were compared with the blood flow at standard position with 0° arm abduction. Maximal systolic flow rate (Vsmax) was fixed at the two points of the chosen abduction position: firstly, in *arteria subclavia* measuring in the point above the clavicle and secondly – in *arteria axillaris* in the medial corner of *fossa axillaris.* Measurements were done firstly by the shoulder in a horizontal plane and secondly – by elevating the shoulder for 8 cm and thus placing the arm in flexion position. The regional anesthesia station „Locoflex 4E" (Latvia) was used for the arm positioning and for monitoring of the support height; it is provided for comfortable placement of the patient arm in the selected abduction, flexion or rotation angle and it ensures a comfort of the patient and doctor during manipulations or examinations (Vasilevskis et al, 2004–2007).

Control group

For the better data interpretation, data from the similar measurements of other authors were selected because the design of our own study did not unforeseen a control group. Thus, for the control group the work of the Sport and Movement Research Institute of Liverpool about the measurements of arterial flow was selected; the design of this study and patient positions are very similar to the profile of our work. The test study carried out by *Stapleton* et al. in 2009 on the diagnostic positions' tests for vascular *thoracic outlet* syndrome used the ultrasonographic measurements of arterial flow. The changes of systolic flow rate and arterial diameter in *arteria subclavia* basin were compared at different abduction positions (Stapleton et al., 2009). Arm positions used in this study corresponded to the arm positions investigated by as.

3. Study on the arterial flow in the arm hyperabduction positions with shoulder depression and arm horizontal extension

37 patients –16 women and 21 men of an average age of 62 ±14 years hospitalized in the Departments of Traumatology and Orthopedics, General Surgery or Internal Medicine participated in the open, comparative study. The effect of perioperative positions on the neurovascular bundle, as well as the comfort level of the patient was evaluated. Patients which can walk and according to the study protocol can do arm hyperabduction tests when lying on the examination table were included in the study. Defined **exclusion criteria** were following: inability to lay supine all the examination time, inability to do the arm abduction attempt up to the position of 120°, patient's weight more than 100 kg, trauma of the shoulder zone or previous surgery on the examined side, arrhythmias and atrial fibrillation, as well as a hypoechogenic type of the tissues that prevents accurate doplerographic examinations. Two of the positions in the examination were associated with 150° and 180° abduction but non-fulfillment of them did not exclude the patient from the study.

The maximal systolic flow rate of *arteria subclavia* and *arteria axillaris* at different positions of arm abduction in four potential compression points was determined, the diameter of arteries was measured and the level of patient comfort was recorded. 36 patients completed the studies because for one patient the position on the examination table was uncomfortable and the examination was interrupted.

The work was done by the portative ultrasound device „Sonosite MICROMAXX" with a 6-13 MHz linear probe. The changes in maximal systolic flow rate (Vsmax) in the arteries were recorded in the special protocol. Examinations were standardized and were done in the predetermined positions of the arm.

The positions of arm abduction used during anesthesia were chosen – 45°, 90°, 120°, 150° and 180°. Precise angle of the arm abduction was achieved by the special pattern placed beneath the patient. The study was started with 45° position because it was not possible to do all ultrasonographic examinations at 0°. The selected parameters were fixed in four potential compression points of the artery: 1. infraclaviculary (INFRA); 2. below the tendon of *m. pectoralis minor* or in the subcorticoid canal (PECT); 3. at the point against *caput humeri* (HUM); 4. in the axillary region (AXILL). Two examination series were performed: in one of them the arm and shoulder was at the level of examination table but in the other - the shoulder and support of the arm was lowered for 6 cm, thus gaining a 30° arm extension. The regional anesthesia station „Locoflex 4E" (Latvia) was used for the arm positioning and for regulation of the height.

First, the maximal systolic flow rate (Vsmax) at the selected abduction positions in the potential compression points of the blood vessels and the artery diameter during diastole was measured. In separate cases, it was not possible to gain the measurements at the 150° and 180° abduction if these positions were very uncomfortable for the patient. If it was difficult for the patient to lay supine, only the examination series with the shoulder at the horizontal level was done.

Secondly, after every measurement the patient was asked to evaluate the position convenience by 0 to 10 points, where 0-2 is very comfortable, 3-4 moderate comfortable, 5-6 troublesome, 7-8 moderate uncomfortable and 9-10 very uncomfortable. In the separate patient group of 20 subjects more precise nature of the complaints and their localization was determined. It was detected at which abduction degrees the complaints appear and at which rating of the position inconvenience the patient develop the complaints. All types of unpleasant symptoms were also recorded.

Control group

For the better data interpretation, data from the similar measurements of other authors were selected because the design of our own study did not unforeseen a control group. Thus, for the control group the work of the Sport and Movement Research Institute of Liverpool about the measurements of arterial flow was selected,

where the design of the study and patient positions are very similar to the profile of our work. The test study carried out by *Stapleton* et al. in 2009 on the diagnostic positions' tests for vascular *thoracic outlet* syndrome used the ultrasonographic measurements of arterial flow. The changes of systolic flow rate and arterial diameter in *arteria subclavia* basin were compared at different abduction positions and clinical symptomatic recorded at the same time (Stapleton et al., 2008). Arm positions used in this study corresponded to the arm positions investigated by as.

4. Assessment of the work habits of anesthesiologists in patient positioning and the comfort level of patient evaluate by the anesthesiologist

In the open, non-comparative study, 31 experienced anesthesiologist (7 women and 24 men) from Latvia (7), France (23) and United Kingdom (1) that generally represent 18 private or state hospitals and are doing anesthesia regularly for 3 to 39 years were polled using a questionnaire. In the questionnaire that consists of 15 questions anesthesiologists was asked to analyze parameters those can effect the course and efficiency of regional anesthesia (RA) and the special attention had to be paid to the assessment of the position of patient and doctor and the comfort level during RA.

First, the doctors were asked to evaluate according to 10-point system fifteen parameters affecting RA: neurostimulator and ultrasonograph, needle quality and its manufacturer, choice of a local anesthetic, static patient position, presence of an assistant or nurse and their experience in regional anesthesia, knowledge of topographic anatomy, a manual of RA, anesthesiologist's comfort during RA when accessing the working area or manipulating by instruments, patient comfort during RA, daily hour time limitations for the method. The parameters were evaluated using 10-point scale from 0 to 10 and were analyzed in such intervals: 0-2: very non-important; 3-4: non-important; 5-6: moderate important; 7-8: important; 9-10: very important.

Secondly, the applied methods used by anesthesiologists for patient positioning in the working position to do arm, leg or perimedullar anesthesia were analyzed.

Thirdly, the patient comfort during RA of the arm or leg using different techniques, as well as during spinal and epidural anesthesia was determined. The comfort level was evaluated using 10-pionts system from 0 to 10 and was analyzed in

such intervals: 0-2: very uncomfortable, 3-4: uncomfortable; 5-6: satisfactory; 7-8: moderate comfortable; 9-10: very comfortable.

Fourthly, the doctor's comfort level during the RA manipulations when performing regional blockades in the arm, leg or perimedullary was evaluated. The comfort level was evaluated using 10-points system from 0 to 10 and was analyzed in such intervals: 0-2: very uncomfortable, 3-4: uncomfortable; 5-6: satisfactory; 7-8: moderate comfortable; 9-10: very comfortable.

Additionally, the role of assistant and nurse and their functions during RA, a place where the RA is done in the operation room and the average time required for carrying out different regional blockades was found out.

5. Development of the technical auxiliary devices for arm positioning during the surgical operation or anesthesia manipulations

The technical auxiliary devices for arm positioning during the operation and anesthesia manipulations was designed according to the experimental-and-error method in Riga in experimental laboratory and in France. In Latvia, it was done in the Riga Hospital No.2 and in the Hospital of Traumatology and Orthopedics. In France, the approbation was carried out mainly in the following clinics: *Roussillon - Clinique Saint Charles*, *Paris - Clinique des Montagnes, Toulouse - Clinique Du Cours Dillon* and *Clermont Ferrand - Clinique Le Pôle Santé République.* The ultrasound probe holder is mainly approbed in *Quency-sous-Sénart – Hospital Privé „Claude Galien".* Totally about 10 clinical samples for the models „Locoflex 1" and „Locoflex 2" and about 15 for the models „Locoflex 4E" and „Echosupport" were developed and approbed up to their successful registration in the Latvian and European register of medical devices and the beginning of their manufacturing. The clinical samples were made and tested simultaneously with patenting of the already developed models. During the clinical tests, doctors had to answer the following questions: convenience of the patient positioning, patient's comfort, doctor's comfort when doing the regional anesthesia, stability of the device end convenience of its maintenance.

6. Identification of the neurological risk for the extremities positioning and working out the recommendations

The scale of neurological risks for the extremities positioning was worked out based on our study and literature data. Six factors mentioned in the literature more

often which are associated with higher incidence of the neurological complications in the postoperative period were selected:

1. Potentially dangerous position time > 2 hours (syndromes caused by compression and strain after an exposition of 2 hours);
2. Previous peripheral neuropathies;
3. Metabolic diseases, decreased tissue trophics, recent trauma or previous prolonged immobilization of the patient or extremity
4. Placing arms or legs on supports during the operation;
5. Using of a tourniquet during the operation.

Basing on the description of the *Double Crush, Reversed Double Crush* and *Multiple Crush* syndromes (Upton, McComas, 1973, Lundborg, 1986), it was supposed that the presence of several risk factors affecting peripheral nerves increases the risk of postoperative neuropathies. On the base of these selected risk factors the risk scale was created. The risk increases by cumulating the risk factors associated with the patient himself (point 2, 3 and 4) or fixed during the operation (point 1, 5 and 6).

Simultaneously, on the base of the study results and literature data the clinical recommendations for arm positioning were developed to improve the patient comfort and reduce the possible neurological complications.

Ethical aspects of the work

The study was done respecting ethical considerations applicable to biomedical studies. The work was done basing on the Helsinki declaration'1964 (Declaration of Helsinki, 1967) and the approvals issued by the Riga Stradins University Ethic Committee for conducting of the studies (Approvals from 10.04.1008 to 14.01.2010).

Before the beginning of two studies with using of ultrasonography, the patients were informed orally and in writing about a course of the study and completed a consent form.

The approval for the biomedical study was obtained also from the directors of all medical institutions (Agreed 09.04.2008 in the Riga Hospital No.2, 28.11.2009 in Ventspils and 19.01.2010 in Jelgava regional hospitals).

Methods of the data statistical processing

Microsoft Excel software was used for data input. Then, the data were converted in the software *SPSS for Windows 16.0* (Company *SPSS*, USA) for further statistical analysis. In

the medical studies generally accepted statistical methods were used for data processing; these are described in several literature (Altman, 2000, Rosner, 2000, Teibe, Berkis, 2001, Krastins, Ciemina, 2003, Krastins, 2003, Teibe, 2007).

Correspondingly to data structure necessary calculations were done. For all nominal scale and categorized values the absolute and relative frequency was calculated and, if necessary, the frequency distribution was represented in diagrams. For the comparison of several categorized variables a chi-square (χ^2) test and tests for evaluation of different proportions were used.

For the variables of proportion scale central tendencies (mean arithmetic, mode and median) and dispersion of the values (standard deviation and mean standard error) were calculated. Advanced hypotheses depending on the data structure were checked using independent samples and paired samples t-test or one-way analysis of variance (ANOVA). Consistency of data for their normal distribution was checked using *Kolmogorov's – Smirnov's* test.

For the evaluation of close correlation between two variables correlation and linear regression analyzes were used. Correlation was considered significant if its coefficient was equal to or more than 0.7. We rejected the null hypothesis if the probability value was equal to or less than 0.05 ($p<0.05$) and accepted it in the opposite case. In some cases, evaluation of the obtained results was also done using 95% confidence intervals. Relationships among variables were evaluated using either Pearson's correlation or Spearman's rank-order correlation with modeling performed using simple linear regression. Pearson's correlation reflects the degree of linear relationship between two variables.

For statistical processing of the **autopsy material** a paired samples t-test for mean values was used. The data obtained only from the autopsy data of seven cadavers were statistically processed during the study because more material was not available in the study period and the gained data already showed a clearly interpretable tendency.

Results

1. Data of the study on the strain and compression of the neurovascular bundle

Strain deformation

In the study on strain deformation, after bilateral denudation of the cadaveric *sulcus bicipitalis,* strain examination of "investigated part" of 23 nerves (*nervus medianus, nervus ulnaris* or *nervus cutaneus brachii*) were performed.

Mean length of the fixated nerve segment was 29.3±6.76 mm at the baseline position 0° that gradually increased during the load up to 31.16±7.27 mm at 90°, 31.28±7.07 at 120° and 31.57±7.37 mm at 180° arm abduction. The most significant strain deformation of the nerve was observed at the position change from 0° to 90° and these changes were statistically significant ($p<0.001$), whereas the arm abduction up to 120°, 150° and 180° provoked less significant deformation, however, the changes at the position from 90° to 180° were still statistically significant ($p<0,05$) (Figure 1).

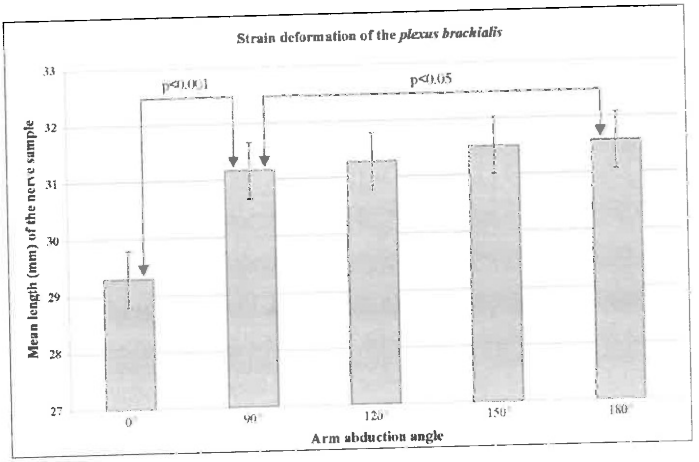


Figure 1. Absolute strain deformation (mm) of the nerve during the arm abduction tests

Conversely, the relative strain deformation during the abduction tests from 0 to 180° ranged from 3 to 23% that was estimated as a wide range. On average, relative deformation of 6.37%± 1,21 at 90° abduction, 6.76% ± 1,23 at 120°, 7.6% ± 1.32 at 150° and 7.76% ± 1.33 at 180° was observed (Figure 2).

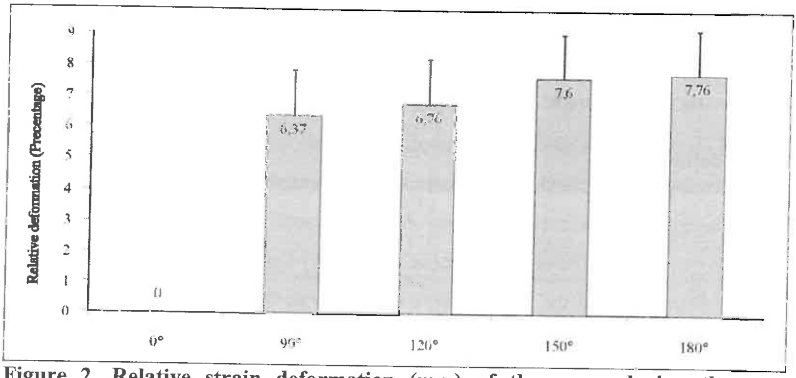


Figure 2. Relative strain deformation (mm) of the nerve during the arm abduction tests

Compression deformation

In the study, *vena brachialis* was catheterized 12 times and *arteria brachialis* one time and totally 13 measurements series were obtained. Catheterization of the blood vessels failed in one case and it was possible to do only the measurements of nerve strain.

The mean pressure change in the dilatation balloon-catheter further transferred into the surrounding tissues increased from 20.22±0.33 kPa (153.7±2.5 mm Hg) at the baseline position 0° to 22.01±1.45 kPa (167.3±11.0 mmHg) at 90° abduction, 27.19±3.17 kPa (206.7±24.1 mmHg) at 120° abduction, 29.88±4.03 kPa (227.1±30.6 mmHg) at 150° abduction and 31.94±5.29 kPa (242.7±40.2 mmHg) at 180° abduction (Figure 3). In absolute numbers the pressure generated in the balloon-catheter that presents a pressure in the neurovascular bundle is 1.79 kPa (13.6±1.8 mmHg) at 90°, 7.07 kPa (53.7±9.1 mmHg) at 120°, 9.66 kPa (73.4±12.4 mmHg) at 150° and 11.72 kPa (89.0±21.3 mmHg) at 180° arm abduction, on average. It was recognized in the study that at the arm abduction position over 120° the tissue pressure exceed 50 mmHg that is regarded as sufficient to cause local ischemia of the tissues or nerve. The increase in pressure was statistically significant in ranges 0-90° ($p<0.001$), 91-120° ($p<0.001$), 121-150° ($p<0.001$), as well as) 151-180° ($p<0.05$).

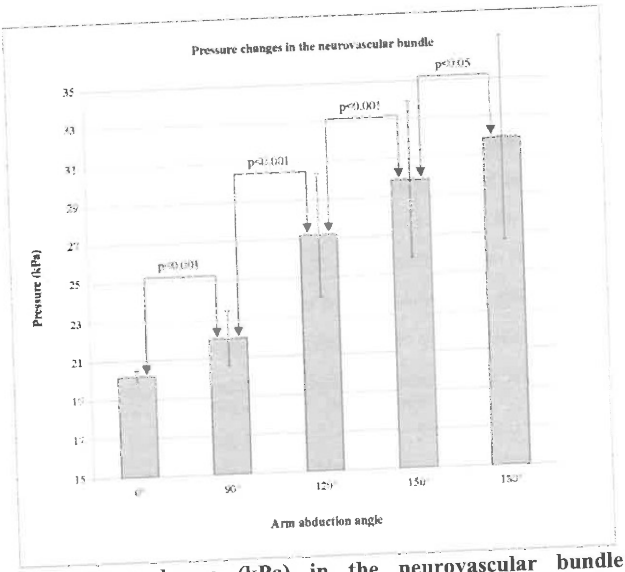


Figure 3. Pressure change (kPa) in the neurovascular bundle in the cervicobrachial part

Light microscopy data of the nerve samples after strain load

In the cross - and longitudinal sections of the nerve slide non-subjected to strain the nerve structure with free capillary lumen, myelin cylinder and axon in its center is well seen. Morphological structure of the nerve slide subjected to strain is changed. Common nerve contour in the longitudinal section is significantly straightened. Myelin cylinders are visually separated from the central axon forming optically empty polygons in the center of which the axon without connection with the myelin cylinder is seen. All in all, comparing the morphological structure of the neural tissues subjected to strain and the control samples the morphological scene confirms a damage of the neural tissues. The contact loss between myelin cylinders and axons caused by a mechanical influence should be considered.

Electron microscopy (EM) data after of the strain test

Transmission electron microscopy (TEM)

The myelinated and unmyelinated nerve fibers were studied ultrastucturally before and after tension. Before the test, some myelinated nerve fibers showed expanded spaces within myelin layer between myelin and myelin membranes, filled

with homogeneous cytosol containing mitochondria. Cytoskeleton elements were well marked and properly oriented in central axis. Numbers of myelin layers within a single nerve fiber were greatly varying. Unmyelinated fibers mostly showed nerve cell processes swelling and mitochondrial degeneration. Microtubules were oriented mostly parallel to the long axis of the nerve fiber. Collagen fibers were observed to be tightly associated with the basement membrane of myelinated nerve fibers.

Disruption of myelin sheets was demonstrated after the specimen tension. EM revealed straightening of myelinated and unmyelinated nerve fibers and surrounding collagen fibers. Cross-sections of unmyelinated nerve fibers were elliptically shaped and showed swollen cytoplasm and slight decrease in a number of cytoskeleton elements.

Scanning electron microscopy (SEM)

Large and small nerve fibers arranged in compact bundles were observed by use of SEM before tension. These nerve bundles were surrounded by collagen fibers. Larger bundles of nerve fibers were enveloped by denser connective tissue.
The nerve fibers became enlarged after application of tension, often having flattened and ribbon-like external appearance. Significant number of nerve fibers was disrupted, and the connective tissue was partly damaged.

2. Measurements of arterial flow in the arm hyperabduction positions with shoulder elevation and arm horizontal flexion

Maximal systolic arterial flow rate (cm/s) in *arteria subclavia* at 0° arm abduction recognized **in the first study part** was 92.62±41.3, at 90° abduction 90.38±30.8 and at 120° abduction 90.6±30.8 cm/s. Changes between 0° and 120° were not estimated as statistically significant (p=0.935). Conversely, the flow rate in *arteria axillaris* increased from 70.19±28.9 at 0° arm abduction to 76.56±29.4 to 91.65±46.4 cm/s in 90° position. Changes in the arterial flow between 0° and 120° were estimated as statistically significant (p=0.008) (Figure 4).

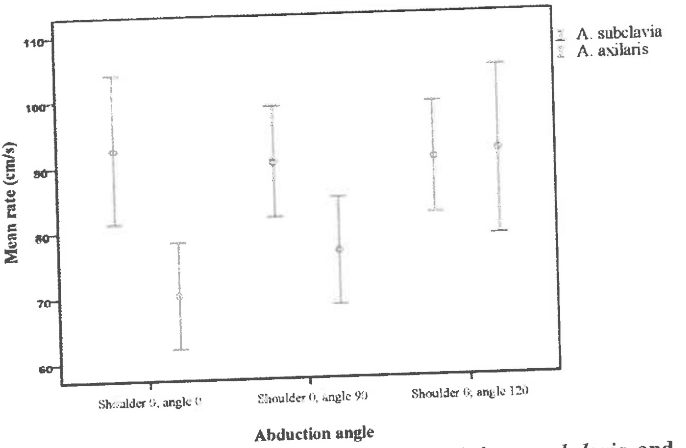


Figure 4. Maximal systolic flow rate (Vsmax) in *a. subclavia* and *a. axillaris* (cm/s) at the 0°, 90° and 120° abduction with the shoulder and arm in the horizontal position

In the second study part, Vsmax in *a. subclavia* and *a. axillaris* was fixed repeatedly in three arm positions additionally elevating the shoulder for 8 cm and placing the arm in 30° flexion position. *Arteria subclavia* showed a tendency of flow decrease, however, it was not statistically significant mostly due to the great individual dispersion of the data. The flow of 96.98±47.6 was fixed at 0° arm abduction, 93.86±36.0 at 90° and 92.98±40.5 cm/s at 120°. . Changes between 0° and 120° were not estimated as statistically significant (p=0.534). The flow of 77.18±34.5 at 0° arm abduction, 79.2±39.3 at 90° and 88.10±37.2 cm/s at 120° was recorded. Changes between 0° and 120° were not recognized as statistically significant because they did not exceed the fixed significance threshold $p<0.05$ but showed clear tendency of the flow increase (p=0.058) (Figure 5).

Conclusions

At the characteristic operation positions in the study and in the control group a poststenotic flow decrease is recognized in the *a. subclavia* and *a. axillaris* basin that may be followed by recurrent flow increase at the compression point but with a smaller flow output value. During the abduction and extension tests, the flow is decreasing in the *arteria subclavia* basin; however, its increase in *arteria axillaris* may be fixed. Flow deceleration is observed next to the stenosis point, but flow increase is observed in stenosis area, that is most commonly a costoclavicular point,

subcoracoid channel, the *arteria axillaris* projection site against the *humerus* head and in the *fossa axillaris*.

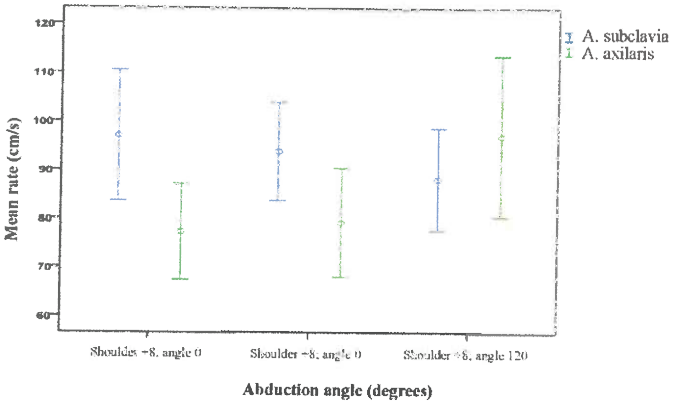


Figure 5. Maximal systolic pressure (Vsmax) in *a. subclavia* and *a. axillaris* (cm/s) at 0°, 90° and 120° arm abduction with the shoulder elevated for +8 cm and arm in 30° flexion.

3. Measurements of arterial flow in the arm hyperabduction positions with shoulder depression and arm horizontal extension

In the first study part, maximal flow rate (Vsmax) in the shoulder arteries in the potential compression points was fixed with the arm in a horizontal plane. The flow increase statistically significantly in the HUM and AXILL points at the arm abduction from 45° to 150°. In the HUM point the flow rate was 64.4±23.4 to 118.8±62.1 cm/s with $p<0.001$ and in the AXILL - 66.8±18.3 to 102.7±41.3 cm/s with a significance $p<0.001$. Conversely, the changes were not significant in the PECT point: 74.8±22.6 to 95.1±11.0 cm/s with $p=0.28$), but then up to 180° started to decrease in HUM, AXILL and PECT points. The exception was an INFRA point where the flow continued to increase also at 180° (45° to 150°: 67.1±20.6 to 72.2±27.8 cm/s with significance $p=0.4$) (Figure 6.).

The positions and measurements up to the 120° abduction were done in all 36 patients, 150° abduction – in 35, but the 180° abduction – only in 30 patients.

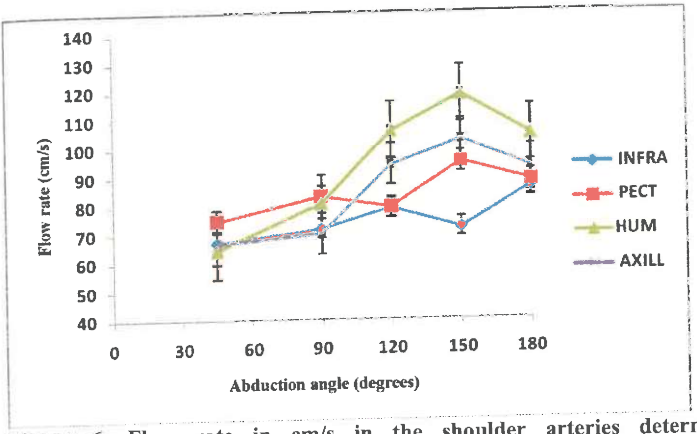


Figure 6. Flow rate in cm/s in the shoulder arteries determined by doplerography in the potential compression points INFRA, PECT, HUM and AXILL for the arm abduction position in the horizontal plane.

In the second study part, Vsmax values in the axillary arteries in the potential compression points with the shoulder depressed for 6 cm and the arm in 30° were determined. It was recognized in these series that if changing the arm position in the range of 45° to 150° the flow increase statistically significant only in the HUM and AXILL points (HUM: from 78.6±32.0 to 142.9±69.4 cm/s with $p<0.001$ and AXILL: from 69.1±21.2 to 108.7±43.2 cm/s with $p<0.05$), but in the INFRA and PECT points the increase was insignificant (INFRA: from 66.2±22.5 to 73.9±35.9 cm/s with $p=0.64$ and PECT: from 74.1±28.7 to 75.7±27.3 cm/s with $p=0.52$) (Figure 7). We recognized that comparing with the measurement with the arm in horizontal level and at 30° extension the change in flow increase in the HUM point in the extension position was significant with $p=0.039$.

45° abduction was done in 26 patients, 90° - in 25, 120° - in 24 and 150° abduction examination was performed in 20 study' participants. The measurements were done in only 2 patients at the 180° position, so this position was not included in the total calculation.

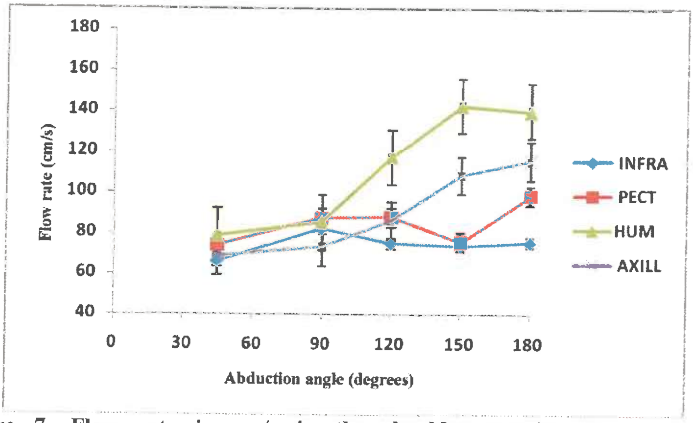


Figure 7. Flow rate in cm/s in the shoulder arteries determined by doplerography in the potential compression points INFRA, PECT, HUM and AXILL for the arm abduction position in the horizontal plane with shoulder depression for 6 cm and 30° arm extension.

In the third study part, changes in the arterial diameter with the arm in a horizontal plane were determined. In the HUM and PECT points changes in the vessel diameter between 45° and 180° positions were statistically significant (HUM: from 0.58±0.12 to 0.48±0.15 cm with $p<0.05$ and PECT: from 0.64±0.13 to 0.6±0.14 cm with $p<0.05$), but in the INFRA and AXILL points there were little but statistically insignificant decrease in diameter (INFRA: from 0.69±0.16 to 0.66±0.15 cm with $p=0.15$ and AXILL: from 0.46±0.08 to 0.45±0.09 cm with $p=0.63$) (Figure 8). Less significant changes were observed between 45° and 150° arm abduction. We recognize that changes in the vessel diameter in the HUM point between the 45° and 150° positions were statistically significant (HUM: from 0.58±0.12 to 0.48±0.14 cm with $p=0.003$), but in the INFRA, PECT and AXILL points the mean diameter decrease insignificantly or even increase (INFRA: from 0.69±0.16 to 0.68±0.14 cm with $p=0.15$, PECT: from 0.64±0.13 to 0.61±0.15 cm with $p=0.025$ and AXILL: from 0.46±0.08 to 0.47±0.1 cm with $p=0.42$).

Positions up to 120° were done by all 36 patients, 150° abduction is done by 34 and 180° - only by 28 patients.

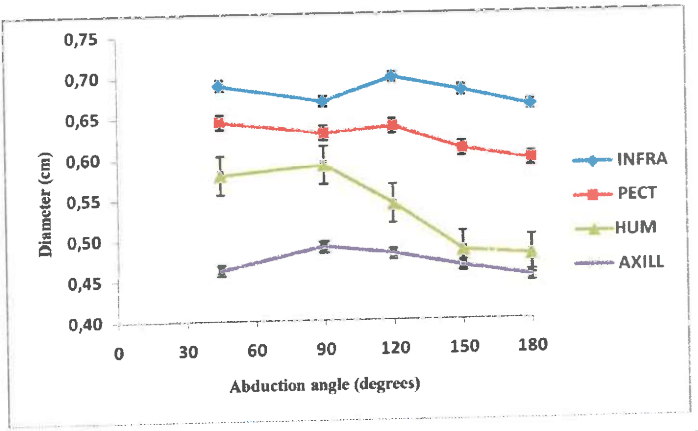


Figure 8. Diameter (cm) of the shoulder arteries determined by doplerography in the potential compression points INFRA, PECT, HUM and AXILL for the arm abduction position in the horizontal plane.

In the forth study part, changes in the arterial diameter with the arm lowered for 6 cm and with arm in 30° extension were determined. It was recognized that changes in the decrease in vessel diameter in the HUM point between 45° and 150° positions were statistically significant (HUM: from 0.55±0.12 to 0.42±0.15 cm with $p<0.001$). In other points the tendency of diameter narrowing was observed, however, it was not statistically significant (INFRA: from 0.72±0.18 to 0.69±0.13 cm with $p=0.23$; PECT: from 0.66±0.16 to 0.61±0.19 cm with $p=0.077$) or even the increase was observed (AXILL: from 0.46±0.09 to 0.48±0.1 cm with $p=0.16$) (Figure 9). Comparing with the measurement where the arm was placed horizontally and in 30° extension. It was recognized that the change in diameter narrowing in the HUM point at the extension position was significant with $p=0.011$.

Positions up to 120° were done by all 23 patients but up to 150° - 20 examined subjects. Examinations at 180° position could be done only by 2 patients and these data were not used in the statistical calculation.

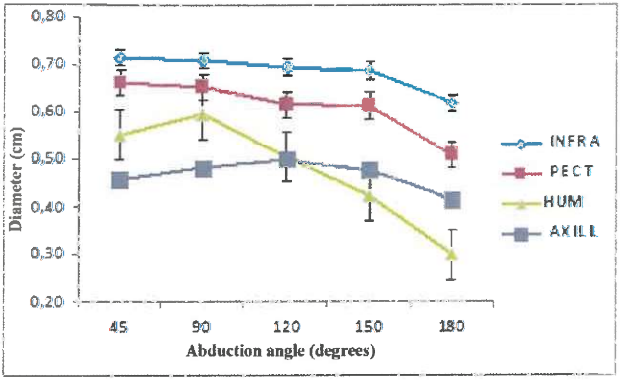


Figure 9. Diameter (cm) of the shoulder arteries determined by doplerography in the potential compression points INFRA, PECT, HUM and AXILL for the arm abduction position in the horizontal plane with shoulder depression for 6 cm and 30° arm extension.

In the fifth part, the patient comfort was analyzed. It was greater in the position with the arm in a horizontal level comparing with arm extension. The positions of 45°, 90°, 120° and 150° abduction with the arm horizontally were evaluated on average by 1.08±0.28, 1.67±0.89, 3.14±1.83 un 4.19±2.4 points, whereas placing the arm in extension worsened the results to 2.81±1.83, 3.40±1.96, 5.04±2.44 and 6.08±1.88 points on average. Comfort at the 180° abduction could be evaluated in statistically significant group only with the arm in horizontal plane and it reaches 4.88±3.25 points. Statistical significance of the changes in position assessment were evaluated as significant in all positions with $p<0.001$ at 45, 90 and 120°, and $p=0.0015$ at 150° abduction comparing the horizontal arm position with 30° arm extension and the shoulder depressed for 6 cm (Figure 10).

Comfort was evaluated in a horizontal plane in 36 patients at 90° arm abduction, in 35 patients – at 120° and 150° and in 30 patients – at 180° abduction. Conversely, if the shoulder was depressed for 6 cm, the 90° and 120° positions were analyzed in 25 patients, 150° - in 20 and 180° - in 3 persons.

Neurological symptoms

More often the complaints appeared at 120° arm abduction but they were sometimes observes also at 45° and 90° abduction. In all cases the complaints appeared already at the arm position in a horizontal plane and intensified at 30° extension. The observed complaints were different. Mostly, the tingling of different

localization predominated that indicates the compression of the neural bundle or peripheral nerves in different points during the abduction. More frequently – five times or in 7.94% cases the patient complained about the hand tingling, tingling in the first three fingers and shoulder pain. Four times or in 6.53% the complaints were about the fingers heaviness, tiredness in all arm and shoulder and discomfort in the arm and feeling of its strain.

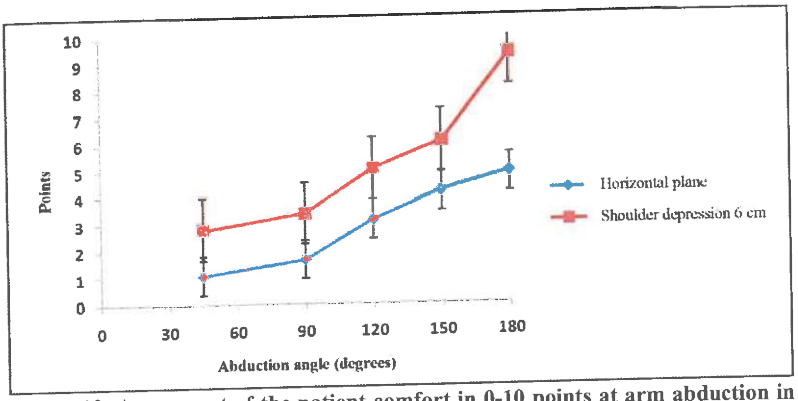


Figure 10. Assessment of the patient comfort in 0-10 points at arm abduction in the positions with the shoulder in the horizontal plane or depressed for -6 cm.

Conclusions

The hypothesis about the decrease of arterial flow in all potential compression points when depressing the shoulder in the case of initially normal flow was not confirmed. Comparing the mean values of the flow in the potential compression points of the shoulder artery at 150° abduction below the clavicle INFRA, PECT and AXILL, the statistically significant flow difference with the arm in a horizontal plane and the shoulder depressed for 6 cm was not observed. Conversely, the change in flow increase was significant in the HUM point in the extension position with $p=0.039$.

The hypothesis about the narrowing of arterial diameter in all positions with depressed shoulder comparing with the arterial diameter with the shoulder in a horizontal position also was not confirmed. However, the narrowing of arterial diameter was significant in the HUM point at 150° abduction with $p=0.011$ when comparing the measurement with the arm and shoulder at horizontal level with the

measurements with the shoulder depressed for 6 cm and simultaneous 30° arm extension.

In the position of arm hyperabduction the abduction plays the main role in compression of the neurovascular bundle and flow changes. At 150° abduction, only the shoulder depression and arm extension redouble compression of the neurovascular with the recognized narrowing of the artery.

Hyperabduction positions of the examined arm was accompanied by varied neurological symptomatic that indicates the stretch of *plexus brachialis* and peripheral nerves and compression during these positions.

4. Assessment of the work habits of anesthesiologists in patient positioning and the comfort level of patient evaluate by the anesthesiologist

It was revealed in the survey that very different aids were used for the arm placement to perform a regional anesthesia (RA). For the placement of arm most frequently the tables of wake-up room - in 25% of cases, tables of the operating room, pillows and soft supports were used or the RA is done without any arm fixation simply placing it on the bed – both in 18%. Less frequently arm supports of the operating room or fixators are used – in 10%, the arm is held by an assistant – in 7%, or other variants is used – in 4%.

From the patient's perspective, none of the used positions was assessed as very comfortable. The positions for performing RA in arm distally – 7.38 and for performing RA in arm proximally – 7.32 points were assessed as moderate comfortable.

From the doctors' perspective their comfort level when performing RA is very comfortable - 8.41 points. During the injection of local anesthetics and when manipulating with syringes the comfort level was assessed as only moderate comfortable -7.77 points, as well as when working with ultrasonograph - 6.75 points.

The obtained results calls to improve patients positioning when performing RA in the arm, as well as offer the universal arm fixators to avoid adapting of materials available in the operating room for the arm positioning in working.

5. Development of the technical auxiliary devices for arm positioning during the surgical operation or anesthesia manipulations

Referring to the author's clinical experience, as well as to the observations when working on the improvement and development of arm fixation devices, an ideal arm support during operation should provide several functions and it should meet some requirements.

Recommended requirements for the arm support:

1. The arm support should be attachable to the entire part of the operation table where the patient's upper body is intended to lay;

2. It is fixated to the universal runners intended for this;

3. Abduction angle of the support may be changed in a wide range from 0 to180° ;

4. It is possible to change a height of the support in a range of -10 to +20 cm against the operation table;

5. The change of the support position against the operation table should ensure 30° flexion and extension and 45° external and internal rotation;

6. It is possible to align the support height and angle from its distal end. It is necessary for the improvement of arm position in the patient who is already covered during the operation and when there are not possible for the doctor to freely access the support fixations at the operating table;

7. The support requires soft, padded cover that is easy-maintained by disinfecting agents, as well as fixating bands are needed for securing;

8. The recommended size of the arm support is 10-15cm x 35-45 cm with a convex sloping surface;

9. Bearing capacity of the arm support should be appropriate for the arm weight (2-5 kg) and firmness in the fixated position.

On the base of the developed patents several device prototypes were created and the clinically introduced device was developed finally that is now used by anesthesiologists for arm positioning during regional anesthesia or for work improvement in regional anesthesia. The regional anesthesia station «Locoflex 4E » development of which was done together by Latvian and French anesthesiologists is introduced into clinical practice (Figure 11).

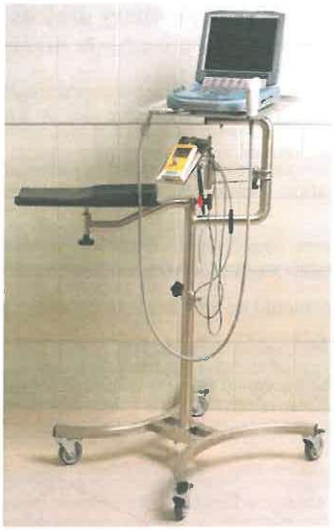


Figure 11. Regional anesthesia station «Locoflex 4E»

This device allows positioning of both arms and legs in selected positions and is independent from the construction and height of the operation table. It may be also used as an extremity support during all the surgical operation. Some additional benefit of the regional anesthesia station is ergonomically construed shelves that allow putting neurostimulators, ultrasonograph and all objects required for venous punctuation or regional anesthesia in the anesthesiologist's working zone. Manufacturing of this device is started and it is used in practice in Latvia, France and Belgium.

6. Identification of the neurological risk for the extremities positioning and working out the recommendations

To reduce the risk of postoperative neuropathies as much as possible, a summary of the risks factors for neurological complications was created referring to

the extensive literature base and the practical recommendations for arm positioning during the surgical operation was worked out.

It is advisable to evaluate all neurological risk factors corresponding to the patient or operation type and record them in the anesthesia card during the anesthesia consultation, pre-anesthesia appointment or latest in the operation room before the beginning of anesthesia. Thus, the *„surgical safety checklist"* or surgical safety control list which is completed in operation rooms (Haynas et al., 2009) and is introduced in many countries by Word Health organization would be perfected. Increasing in the number of risk factors enchases also the number of postoperative neuropathies. Our proposed gradation is following: 1-2 factors: low risk of the neurological complications; 3-4 factors: increased risk of the neurological complications; 5-6 factors: high risk of the neurological complications.

General practical recommendations for an anesthesiologist, surgeon and anesthesia nurse:

1. During the operation, especially in the case of increased neurological risk, controllable risk-increasing conditions such as hypovolemia (Stoelting, 1993), dehydratation, hypotension (Garrique, 1897), hypoxia and electrolyte imbalance (Bartholomew, 1956), and hypothermia (Delorme, 1956, Swan et al., 1953) should be avoided where possible.
2. In practice, an anesthesiologist and anesthesia nurse is more responsible for arm positioning, whereas the leg positioning is supervised both by a surgeon and anesthesiologist. The legal responsibility would be borne by both specialists.
3. All positioning actions should be fixed in the anesthesia card. Thus, it is possible to show that all the necessary actions for risk prevention have been done. Simple table and pictogram is offered that is possible to integrate in the anesthesia card. Assessment of the neurological, as well as performed actions during the positioning can be noted in it (Figure 12). The table and pictogram can be stolen in the anesthesia card. It should be taking into account that the patient positioning time on the operation table and the beginning and end of the operation may differ.

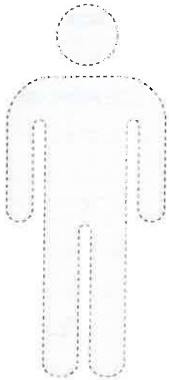
Risk factors	+/–	Position pictogram
Position time on the operation table >2h		Dorsal Ventral Lateral  Dexter Siniser
Previous peripheral neuropathies		
Metabolic diseases, recent trauma or prolonged immobilization		
Age >80 years		
Placing arms or legs on supports		
Using of a tourniquet		
Risk assessment (factors) **1–2 Low; 3–4 Medium; 4–6 High**	1–6	**Beginning of anesthesia** _____ **End of anesthesia** _____

Figure 12. Description of the patient position during the operation and the assessment of neurological risk depending on the number of risk factors. 1-2: Low risk of peripheral neurological complications. 3-4: Higher risk. 5-6: High risk.

Discussion

1. Strain deformation of nerves

For now, there are no data published that would be gained by measuring a pressure directly in the shoulder neurovascular bundle both at rest and during the movements of arm and shoulder. Usually a pressure was measured in the extremity and it is an external pressure, for example, created by a tourniquet (Fowler et al., 1972, Ochoa et al., 1972, Pedowitz et al., 1991) or other compression devices (Horiuchi, 1983, Dahlin et al., 1984, Dyck et al., 1990, Rydevik, Lundborg, 1977).

Little research was done also on the human nerve strain properties. Mostly, the strain properties of nerve sample obtained from the laboratory animals (Kitamura et al., 1995) or a nerve excursion range of the animal of cadaveric material during the movements of extremity (McLellan, 1975, McLellan, Swash, 1976, Wilgis, Murphy, 1986) was investigated.

In the study, the nerve strain deformation was measured directly on the cadaver hand during its abduction. These results provide the information about the degree of nerve strain during abduction and allow comparing our data on the changes in nerve conductivity and tissues with the similar strain degree in the laboratory animals (Kwan et al., 1992, Singh et al., 2008). It was previously recognized in the studies on the traction effect on vessel blood supply that 5-10% traction ceases venous flow and 11-18% ceases microcirculation and arterial extrafascicular supply (Lundborg 1973). It was observed during the promotion work that the mean relative traction forces (6-8%) correspond to the break of venous circulation, but maximal observed values (15-20%) could cause microcirculatory disorders and nerve ischemia. Such date again make careful when placing patient's arm in potential traction positions starting from 90° abduction. It is interesting that investigating changes in the separate *plexus brachialis* parts we recognized that these are not homogenous - similar as in the *Kitamura* study when 80% abduction was performed to the rat extremities (Kitamura, 1995). It may be seen in his work that the circulation disbalance is observed between the nerves in the center and periphery of the plexus. This is explained also with the variation neurological clinics in abduction positions observed in the study that is possibly related to the individual peculiarities of the nerve location in centre or periphery of the plexus (Kitamura, 1995).

2. Compression deformation of nerves

The new approach was used when investigating pathophysiological aspects of the nerve compression. It was possible by the using method patented during the work for the measuring of tissue pressure (Vasilevskis, Vanags, 2010) to determine directly the pressure changes in the neurovascular bundle. The described method is also applicable in further experiments to obtain additionally data using laboratory animals about the pressure change in the neurovascular bundle both when changing a position of shoulder and arm and changing a position of the body, for example, prone and sideward. Such data would be useful for optimal patient positioning during operation. Furthermore, the described method would be used also in the research of other problems such as the pressure determination during the process of bedsores development, in compartment syndrome, in cardiogene and nephritic peripheral edema and in other cases.

Already previously pressures causing the nerve microcirculation changes during compressions leading to ischemia are investigated. It is known that the applied external pressure of 20-30 mmHg ceases arteriolar and intrafascicular capillary flow, but at the 60-80 mmHg pressure the nerve supply is broken completely (Rydevik et al., 1981). The study results approved hypothesis that at the abduction of more than 90° the pressure in the bundle rises rapidly and at 120° the difference between pressures measured before and after the abduction reached 53 mmHg, at 150° - 73 mmHg and at 180° - 86 mmHg. Such pressures actually causes initial cease of the microcirculation and further also arterial flow in the compression area because, comparing with the data given by *Rydevik,* venous compression at 120° abduction and the significant microcirculatory disorders at 150° un 180° abduction should be observed. Critique that may be expressed about these data relates more likely to the appearing of cadaverous stiffness during examination. It should affect minimally the mechanical properties of nerve strain, whereas it may significantly affect the pressure measurement in the presence of muscle tissues. Especially it would relate to the measurements of interscalene space where the muscle stiffness may increase a pressure on the balloon-catheter.

3. Doplerographic examinations of *a. subclavia* and *a. axillaris* and compression of the neurovascular bundle

One of the study tasks was to identify compression point of the neurovascular bundle at different arm positions during the operation. This task is difficult to meet in the experimentally –diagnostic field, because the zone is difficult to access with ultrasonography due to location of the clavicle, it is not possible to simulate all operation positions of the arm by CT and MRI and angiography is hard to perform in volunteers doe to its caused radiation and effect of the contrast substance. In literature, there are few targeted ultrasonographic examinations on the shoulder neurovascular bundle at the abduction positions, therefore our and control group's data have to be compared also with the results of CT, MRI and angiography.

For the analysis of obtained results the *Hagen-Poiseuille* fluid flow law was used; it attributes an increase in flow to vessel narrowing and decrease in flow – with poststenotic extension. In addition, in the theoretical pattern the vessel should narrow for at 50% to observe a significant flow increase (Spencer, Reid, 1979). Consequently, not all cases showing significant narrowing of the diameter but are smaller than 50% relate to the flow increase. In the *Spencer* and *Reid* model the

critical flow threshold was achieved at 20% decrease in diameter. Regarding the work tasks, there is also a significant fact that a compression of artery may also mean a compression of veins and neural bundle because they are located near to each other in the common fasciae space in the shoulder area, although anatomically their position against the artery is variable.

The first experiment observed *a. subclavia* in the flow point above the clavicle comparing with *Stapleton* control group in which the measurements were done under the clavicle. The obtained results of the measurements above the clavicle at 90° and 120° abduction showed a tendency of *arteria subclavia* narrowing with the decrease in flow after the stenosis point passing the attachment site of *mm. scaleni* to the first rib. In turn, the flow decrease under the clavicle indirectly indicates stenosis in the costoclavicular point, and this decrease was significant at 90° and 120° abduction with 30° extension and 90° external rotation, as well as at 180° abduction. However, the changes in artery diameter are not found because the measurement is not done against the stenosis point. These data correlates with the CT and MRI data of *Matsumura* un *Remy-Jardin* (Matsumura 1997, Remy-Jardin 1997) about the compression points between *mm. scaleni* and in the costoclavicular point. Similar data are found also in other available ultrasonographic studies (Longley et al., 1992, Napoli et al., 1993).

In the second experiment, the flow in *a. axillaris* was measured in 4 points under the clavicle and in the *Stapleon* control group distally to the *humerus* head. The results convincingly showed flow increase at 150° abduction with 30° extension in the promotion study and at 120° abduction with and without 30° extension in the control group. In both cases the flow significantly increase in the point measured in the axillary fosse that still corresponds to stenosis zone after the compression against *humerus* head because otherwise the poststenotic decrease in flow should be observed. An artery's compression also against the *humerus* head describes the works of *Dijkstra* and *Westra* that shows *humerus* dislocation ventrally and increased compression of the artery at arm extension and external rotation. Similar *humerus* dislocation is observed in the insufficiency of anterior part of the glenohumeral ligaments (Dijkstra, Westra, 1978). The obtained data put the abduction role in compression of the neurovascular bundle in the first place because the extension intensified compression signs only at 120° and 150° abduction. The study and control

group also showed that the arm flexion with or without arm abduction do not improve arterial flow rates in the shoulder zone (Stapleton et al., 2008).

Neurological clinical symptoms obtained in the study correlates with the control group and studies conducted by *Rayan* on the clinical symptoms in healthy subjects during the *Thoracic outlet* provocation tests (Rayan 1995). Different symptoms associated with the position were obtained which related both to nerve compression and strain and to an uncomfortable position of the shoulder and elbow joints.

4. Assessment of the perioperative neurological risk

To facilitate and organize the anesthesiologist's work increasingly the "*checklist*" or control lists are introduced. In USA, control lists of the anesthesia equipment are used since 1986 and their improvement still continues (Manley 1996, Blike, Biddle, 2000). Checklists of the anesthesia equipment are developed also in Europe (Nilsson et al., 2009). Also in this promotion work, one of the tasks were development of the methods for reduction complications which actually appears due to incorrect execution of patient positioning according to already known rules already mentioned in manuals (Desmonts, 1994, Samii, 1995, Sawyer et al., 2000). The task is facilitated by the fact that in recent years the World Health Organization has started to introduce the „*surgical safety checklist*" or control list of the surgical safety (Haynas et al., 2009).

After identification of the main six neurological risk factors, the idea occurred to integrate patient positioning and assessment of the risk factors into the perioperative control list of the surgical safety.

The results gained during the promotion work confirm the rules of patient positioning and monitoring described previously in the literature (Desmonts, 1994, Samii, 1995, Sawyer et al., 2000, Ullrich et al., 1997, Eurin, 2002). However, the data obtained in the study significantly expands the understanding of the pathophysiological processes in the neurovascular bundle which cause a strain and compression deformation of nerves during different arm movements and with a lasting impact and in the presence of predisposing factors may lead to postoperative neuropathies (Upton, McComas, 1973). The developed devices for arm positioning and introducing of the postoperative neurological risk scale in the practice will help to improve patient comfort and will reduce postoperative complications.

Conclusions

1. The main pathogenetic factor of postoperative *plexus brachialis* neuropathy is the strain and compression deformation of the peripheral nerves in combination with the long exposition time.

2. Poststenotic flow decrease of *a. subclavia* is detected at the abduction of 90 ° and 120° and at the 30° extension distal to the attachment site of *mm. scaleni* ; significant compression of *a. axillaris* occurs at 150° abduction and 30° extension at the points against the *humerus* head and in axillary fosse.

3. The patients comfort level is higher in the position with the arm in horizontal level comparing with the positions with shoulder depression for 6 cm and 30° extension.

4. The technical auxiliary device "Locoflex 4E" is developed and patented to improve the positioning of the arm and patient comfort.

5. Six neurological risk factors associated with positioning is recognized: position time on the operation table > 2h, previous peripheral neuropathies, metabolic diseases, decreased tissue tropics, recent trauma or previous prolonged immobilization, age > 80 years, placing arms or legs on supports, using of a tourniquet.

6. To reduce the neurological risk the perioperative neurological risk scale were created and general practical recommendations for patient positioning supine, prone and sideward during an operation.

Clinical recommendations

To reduce the risk of postoperative neuropathies the new perioperative neuropathies risk scale is developed. Together with already used control list of the surgical safety (Haynes, 2009) introduced by the World Health Organization it should be used for the assessment and prevention of neuropathy risk. Simple table and pictogram is offered that is possible to integrate in the anesthesia card. Assessment of the neurological risk, as well as performed actions during the positioning can be noted in it. The table and pictogram can be paste in the anesthesia card. The practical use of it is already started at the pilot study and their further introducing will be possible in the near future.

Other practical investment of the work is associated with the introducing of the arm positioning device „Locoflex 4E" that improves the arm positioning

conditions and are especially useful in regional anesthesia. This device allows positioning of both arms and legs in selected positions and is independent from the construction and height of the operation table. Thanks to this device, is also possible to put neurostimulators, ultrasonograph and all objects required for venous puncture or regional anesthesia in the anesthesiologist's working zone.

Device „Echosupport" is also started to use in clinical practice that improves doctor's comfort when performing regional anesthesia under the ultrasound control. These devices are successfully used in several centers in Latvia and France since 2008.

Ensuring of the patient safety during the operation, including the care of his position and comfort is a collective task of anesthesiologists, surgeons and all the personal of operation department. The developed methods and devices serve this collective purpose and certainly will be investigated more comprehensive and widely in the future.

List of publications

Monographs

1. E. Vasiļevskis, « Anesteziolo̧ijas rokasgrāmata ». Rīga: «Nacionalais Medicīnas Apgāds», 2000. - 550 lpp.

2. E. Vasiļevskis.« Reģionālās anestēzijas ABC ». Rīga: «Nacionalais Apgāds», 2008. - 124 lpp.

Chapter in the textbook

Perifēro nervu bloki. Sadaļa grāmatā "Anesteziolo̧ija, reanimācija, intensīvā terapija", Prof. I. Vanaga un A. Sondores redakcijā; Rīga: Nacionālais Apgāds. 2008, 370-388. lpp.

Publications

1. E. Vasiļevskis. Plexus brachialis multistimulācijas blokāde brachiālaja kanālā: lietošanas pieredze // Acta Chirurgica Latviensis, p. 115 –123., III.2003.

2. E. Vasiļevskis, A. Miščuks, I. Vanags. Special devices for regional anesthesia // Proceedings of the Latvian Academy of Sciences; 148-155, Vol 62, Number 4/5, 2008.

3. E.Vasiļevskis, A.Miščuks, I.Vanags. Reģionālās anestēzijas efektivitāti ietekmējošo faktoru analīze. 2007 RSU zinātniskie raksti; 111-117.

4. A. Miščuks , T. Kauliņš, E. Vasiļevskis, M.Mihelsons. Reģionālās anestēzijas kvalitātes monitorings un tā optimizācija. LU vēstis 2009, 750. sējums; 88-93 lpp.

5. E. Vasiļevskis , M. Radziņa, I. Evansa, U. Teibe, I. Vanags. Arteriālās plūsmas un artērijas diametra izmaiņas kostoklavikulāri-aksilārajā zonā anestēzijas laikā dažādās rokas abdukcijas pozīcijās. // In press; RSU 2010. gada rakstu krājums.

6. E.Vasilevskis, S. Skuja, I.Evansa, E. Šteina, A. Sondore Pīlipa, G. Vābels, U.Teibe, H.Jansons, V. Groma, I. Vanags. *Plexus brachialis* strain and compression deformation in costo-axillary-brachial region: cadaveric study // In press; „Medicina", Kaunas, Lithuania..

Reports in conferences regarding the results

1. E. Vasilevskis , A. Miscuks. Optimisation of upper limb peripheral nerve block. Referāts. 4th International Baltic congress of anaesthesiology and intensive care. Rīga, 2008. gada 11-13. decembris.

2. E. Vasilevskis , A. Miscuks, M. Radzina, I. Vanags, H. Jansons . Blood flow changes in subclavian and axillary artery during hyperabduction of the arm in normal and elevated shoulder positions. Stenda refwerāts. NYSORA World anesthesia congres, Dubai, 7-12. III 2010.

3. E. Vasilevskis , A. Miscuks, M. Radzina, I. Vanags, H. Jansons . A. *subclavia* un *a. axillaris* sistoliskās asins plūsmas, artērijas diametra un pacienta komforta izmaiņas pie dažādām rokas pozīcijām anestēzijas laikā // RSU zinātniskā konference, 2010. gada aprīlī.

4. E.Vasilevskis, G. Vābels, , I.Evansa, A. Miščuks, E. Šteina, A. Sondore-Pīlipa, U.Teibe, I. Vanags, H. Jansons. *Brachial plexus* and vascular bundle compression and tension deformation during the hyperabduction of the arm. Stenda referāts ESRA Eiropas reģionālajā kongresā, Rīga, 2010. gada 20.-22. maijs.

Patents

1. Vasiļevskis E., Vanags I., Ierīce augšējās ekstremitātes operācijām, // Latvijas Republikas patentu valde, 20. oktobris 2004, patents LV 13204 B.
2. Vasiļevskis E., Vasiļevskis L. Ierīce lokoreģionālai anestēzijai // Latvijas Republikas patentu valde, 20. decembris 2004, patents LV 13224 B.
3. Vasilevskis E. Device for locoregional anesthesia // World Intellectual Property Organization, 19. January 2006, International Publication Number WO 2006/006836 A1, International Patent Classification: A61G 13/12, A61M 5/52, International Application Number: PCT/LV2005/000002, International Filing Date: 8 March 2005 (08.03.2005), Priority Data: P-04-76, 9 July 2004 (09.07.2004) LV.
4. Vasiļevskis E. Ierīce lokoreģionālai anestēzijai // Latvijas Republikas patentu valde, 20. augusts 2006, patents LV 13375 B.
5. Vasiļevskis E., Ramanis M. Ierīce lokoreģionālajai anestēzijai // Latvijas Republikas patentu valde, 20. maijs 2007; patents LV 13563 A.
6. Vasiļevskis E., Ramanis M., Eglītis A. Ierīce lokoreģionālajai anestēzijai // Latvijas Republikas patentu valde, 20. decembris 2007; patents LV 13652 B.
7. Vasiļevskis E., Ramanis M., Eglītis A. Ierīces lokoreģionālajai anestēzijai dizainparauga reģistrācija // Latvijas Republikas patentu valde, 20. janvāris 2009; reģistrācijas apliecība D 15 229.
8. Vasiļevskis E., Ramanis M. Ultrasonogrāfa zondes fiksators // Latvijas Republikas patentu valde, 20. jūlijs 2010; patents LV 14151 B.
9. Vasiļevskis E., Vanags I. Ierīce audu spiediena mērīšanai // Latvijas Republikas patentu valde, 20. decembris 2010; patents LV 1412 B.

Developed and implemented devices

1. Device for regional anesthesia „Locoflex 2".
2. Device for regional anesthesia „Locoflex 4E".
3. Device for ultrasound probe fixation „Echosupport".

Study protocol No.1

Doplerography of the blood vessels of upper extremity

- **Patient:** **Date:**
- **Age:** **ASA:**

- **Weight:** **Height:** **BMI:**

Pathology of the spinal cord or shoulder area:

- **Mobility of the neck and shoulders:**

- **Operation / trauma:**

	Right arm				Left arm			
	1 Subcl	2 Axill	1 Subcl +8cm	2 Axill +8cm	1 Subcl	2 Axill	1 Subcl +8 cm	2 Axill + 8cm
DD Arm at side								
Abduction 90°								
Hands behind head, abduction 120°								

Comments:

Doplerography of the blood vessels of upper extremity

- **Patient:** **Date:**
- **Age:** **ASA:** **No:**
- **Weight:** **Height:** **BMI:**

- **Operation / trauma: (Disease)**

Arm in abduction	A. Subclavia / A. axillaris Right / Left / VA / RA				
	Infraclavic / I rib	M. pect. minor / Hum.		Axillaris	Comfort 1-10
	0° shoulder and arm horizontally				
45° V					
Dø					
90° V					
Dø					
120° V					
Dø					
150° V					
Dø					
180° V					
Dø					
	Shoulder -6 cm, arm in 30°extension				
45° V					
Dø					
90° V					
Dø					
120° V					
Dø					
150° V					
Dø					
180° V					
Dø					